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Proceedings of Symposium on Ultrasonic Electronics, Vol. 37 (2016)

16-18 November, 2016

A Fundamental Study on Measurement of Elastic Properties in Compacted Bentonite by Ultrasonic Velocity Measurement

超音波音速計測による圧縮ベントナイトの弾性特性計測に関する基礎研究

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1. Introduction

One of the important issues of nuclear power is how to deal appropriately with the high-level radioactive waste (HLW). The HLW contains high level radioactivity and various types of long-lived nuclides. The HLW should be isolated from the human environment for a very long time period by a combination of engineered and natural geological barriers since the radioactivity will remain for more than 10,000 years. The engineered barriers consist of the vitrified glass, overpack, and buffer material. For example, buffer material is installed at the outermost part of the engineered barriers to provide stable chemical and physical environment for inner engineered barriers. Bentonite, which is a clay material, is considered to be a good candidate for the buffer material of geological disposal because of its swelling property, low water permeability and low diffusion for nuclides. Bentonite is planned to be compacted and installed in the disposal repository. Understanding groundwater behavior inside compacted bentonite is the most important issue for evaluation of radionuclides transfer for long-term safety. Recently, the effect of water content on elastic properties of compacted bentonite has been investigated by ultrasonic velocity measurement[1]. However, this effect has not been investigated in detail because bentonite has inhomogeneous structure. In addition, bentonite properties which affect ultrasonic velocity have not been studied well. In this study for developing the evaluation method for elastic properties of compacted bentonite, the effect of water content and dry density on the ultrasonic velocity was investigated experimentally.

2. Experimental methodology

2.1 Specimen preparation

The sample material of pure smectic bentonite powder (Kunipia-F) was prepared for the compacted specimen. The procedure of preparation was as follows. Bentonite was dried for 24 hours at the temperature of 110°C. Pure water was added to the dried bentonite to adjust water content. Water content W_c is defined as

$$W_c = \frac{M_w}{M_s} \tag{1}$$

Where M_w is the mass of water and M_s is the mass of bentonite. The sample has three levels of water content: ~19%, ~22%, and ~26%. Then, the bentonite powder is put into a cylindrical mold, and is compacted from both ends of the pipe. Specimens have a diameter of 28 mm and a length of from 10 mm to 16 mm. Dry density of specimens are between 1.00 g/cm^3 to 1.70 g/cm^3. These cylindrical compacted bentonite specimens were prepared to investigate the effect of the water content variation and dry density variation.

2.2 Experiment apparatus

The experimental apparatus consists of two ultrasonic transducer (B0.1K20N, Japan Probe Co., Ltd.), a pulser/receiver (JPR-10CN, Japan Probe Co., Ltd.), a computer, and an external amplifier (PR-60A5, Japan Probe Co., Ltd.). The transducer has an element with a diameter of 20 mm. The center frequency of the transducer is 100 kHz. The transducer was installed at both ends of a specimen. Ultrasonic wave was emitted into the specimen from a surface and was received on an opposite surface. The pulser/receiver was used for a transducer control by changing voltage and center frequency of emitting wave. The frequency of emitting wave was 100 kHz.

2.3 Group velocity determination

In order to obtain the velocity of bentonite, group delays were calculated. Group delay can be calculated from a reference signal $r(t)$ and a transmitted signal $t(t)$ as follows.

$$\begin{aligned} R(\omega) &= \int_{-\infty}^{+\infty} r(t) e^{-i\omega t} dt \\ &= |R(\omega)| e^{-i\phi_r(\omega)} \end{aligned} \tag{2}$$

$$\begin{aligned} T(\omega) &= \int_{-\infty}^{+\infty} t(t) e^{-i\omega t} dt \\ &= |T(\omega)| e^{-i\phi_t(\omega)} \end{aligned} \tag{3}$$

$$\mathrm{t_g}(\omega) = \frac{d}{d\omega}(\phi_t - \phi_r) \tag{4}$$

Where ω is angular frequency. $R(\omega)$ and $T(\omega)$ are Fourier transforms of reference signal and transmitted signal, respectively. $\phi_{t(\omega)}$, $\phi_r(\omega)$, and $t_g(\omega)$ are phase of reference signal, phase of transmitted signal, and group delay.

Group delay can be obtained from a phase difference of reference signal and transmitted signal by Eq. (4). Delay time was obtained by averaging group delay between 0.05 MHz to 0.2 MHz. Group velocity of bentonite can be determined from group this delay time. In this study, the reference signal was measured using cylindrical polystyrene specimens and then initial phase was calibrated.

3. Results and Discussions

Figure 1 shows a time-domain profile and a Fourier amplitude of transmitted-signal of bentonite. For the Fourier transform, the original signal was filtered by Hanning window in order to separate the first peak of around 40μs in **Fig.1 (a)**. **Figure 2** represents the group delay of the bentonite. Red line in **Fig.2** shows the angular frequency range from 0.05 MHz to 0.2 MHz. This range was determined from Fourier amplitude of -50 dB or more in **Fig.1 (b)**. The group velocity was calculated from the averaged delay time and length of the specimen. **Figure 3** shows Group velocity variation of bentonite with varying water content and dry density. The vertical axis indicates the group velocity, and the horizontal axis indicates the dry density of compacted bentonite. From this result, the difference of group velocity does not depend on the water content for the dry density of 1.40g/cm^3 or less. On the other hand, the group velocity increase strongly with increasing water content for a dry density of 1.40g/cm^3 or more. Consequently, the water content variation can be detected by measuring group velocity under the high-dry density condition.

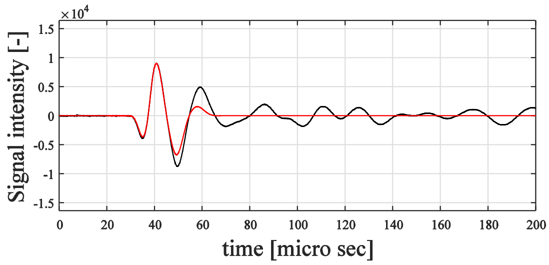
4. Conclusion

In order to develop the evaluation method for elastic property of compacted bentonite using ultrasound, ultrasonic velocity measurement of compacted bentonite was conducted with varying water content and dry density. Group delay was calculated between reference signal and transmitted-signal, and then group velocity was obtained. As a result, the effect of water content on elastic property was measured for a dry density of 1.40g/cm^3 or more.

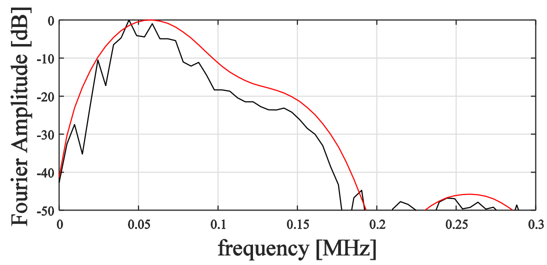
Shear wave velocity is to be measured and a velocity anisotropy of the compacted bentonite is to be also investigated in a future work.

References

1. N. Tisato, S. Marelli., J. Geophys. Res.: Solid Earth **118** (2013) 3380-3393.



(a) Time-domain profile.



(b) Fourier amplitude.

Fig.1. Transmitted signal of bentonite. Black line represents the original signal. Red line represents the signal filtered by the Hanning window.

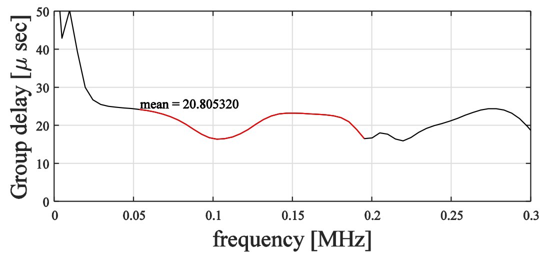


Fig.2. Group delay of the bentonite. Red line shows the angular frequency range from 0.05 MHz to 0.2 MHz.

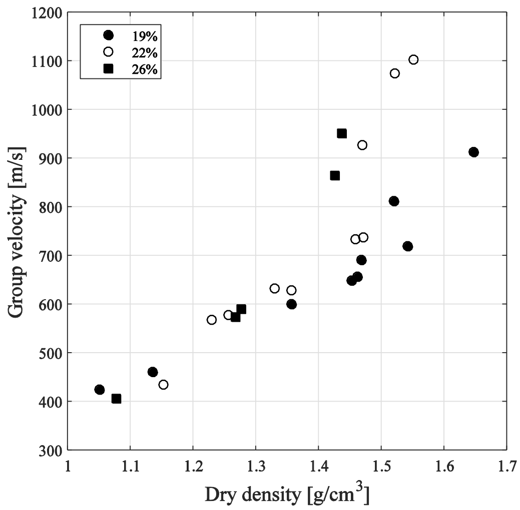


Fig.3. Velocity variation of bentonite with varying water content and dry density. Black circles, white circles, and black squares are W_c of 19%, 22%, and 26%, respectively.